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Comment on "Tropospheric ozone derived from TOMS/SBUV measurements during TRACE A" by J. Fishman et al.

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Recently, *Fishman et al.* [1996] combined Nimbus 7 total ozone mapping spectrometer (TOMS) total ozone with vertical ozone profiles from the NOAA 11 solar backscatter ultraviolet 2 (SBUV2) instrument in an effort to estimate tropospheric ozone residuals (TOR). They included tropopause height fields from the National Meteorological Center (NMC) to calculate stratospheric column ozone from the SBUV2 profiles. TOR was then calculated by subtracting stratospheric column ozone from TOMS total ozone. We note that this same method for deriving TOR was used earlier by *Vukovich et al.* [1996]. A more recent study by *Vukovich et al.* [1997] describes the potentially large errors using this method by comparing one-to-one with ground-based ozonesonde data. In our short comment we focus on tropical latitudes and illustrate that significant errors arise in stratospheric column ozone derived from SBUV because of the combination of vertical weighting functions and the inversion algorithm.

Using the TOMS/SBUV2 (both version 6) combination to derive TOR appeared to be an improvement from the combination of TOMS and Stratospheric Aerosol and Gas Experiment (SAGE) given by *Fishman et al.* [1987, 1991, 1992]. The usefulness of incorporating SBUV2 ozone profiles to determine TOR is obvious; horizontal coverage is global compared with SAGE, which is a solar occultation instrument that restricts daily data to two (sunrise and sunset) narrow 5°-10°latitude bands. Paucity of SAGE measurements is a limiting factor in deriving TOR on a daily, weekly, or even monthly timescale. In contrast, SBUV2, a polar-orbiting and nadir-viewing (straight downward) instrument, makes approximately 14 orbits per day, providing coverage over most of the Earth.

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The purpose of this comment is to point out that care should be exercised when deriving stratospheric column ozone from SBUV. Determination of ozone profiles from SBUV depends critically on the shapes of SBUV vertical weighting functions, which below the ozone number density peak (near 20-25 km altitude) provide diminished information on the distribution of ozone. Ozone inferred at these lower altitudes depends greatly on measurements of total column ozone that are used in deriving a priori profiles for the SBUV inversion algorithm. As a result, this total ozone bias effect can produce large errors in lower stratospheric ozone measurements.

One example clearly demonstrating this SBUV algorithm problem comes from a well-known zonal wave anomaly in total ozone centered in the tropical south Atlantic region that shows evidence of being generated mostly by tropospheric ozone [see, for example, *Fishman et al.*, 1991, 1992; *Ziemke et al.*, 1996]. This anomaly, primarily a zonal wavenumber 1 pattern, is highly stationary in the horizontal plane and persists year round, as was indicated by *Shiotani* [1992], *Stanford et al.* [1995], and *Ziemke and Chandra* [1997], in versions 5, 6, and 7 TOMS total ozone, respectively. All of these latter studies quantified the space-time structure of the wave, showing further that the largest (smallest) amplitudes occur around September-October (May-June), with peak-to-peak values on average ~20 Dobson units (DU) (~10 DU).

As a typical illustration of this persistent wave, Figure 1 compares tropical zonal anomalies (zonal means subtracted) between (top) Nimbus 7 TOMS version 7 total ozone and (bottom) NOAA 11 SBUV2 0.3- to 100-hPa integrated version 6 stratospheric column ozone averaged over several months during southern hemisphere spring. In Figure 1, the zonal wave 1 pattern in TOMS is around 25 DU peak to peak. In low latitudes the tropopause lies around 100 hPa, suggesting that if SBUV2 is accurate throughout the stratosphere down to 100 hPa, then Figure 1 indicates that there should be an ~13-15 DU (peak-to-peak) contribution to the wave coming from stratospheric ozone.

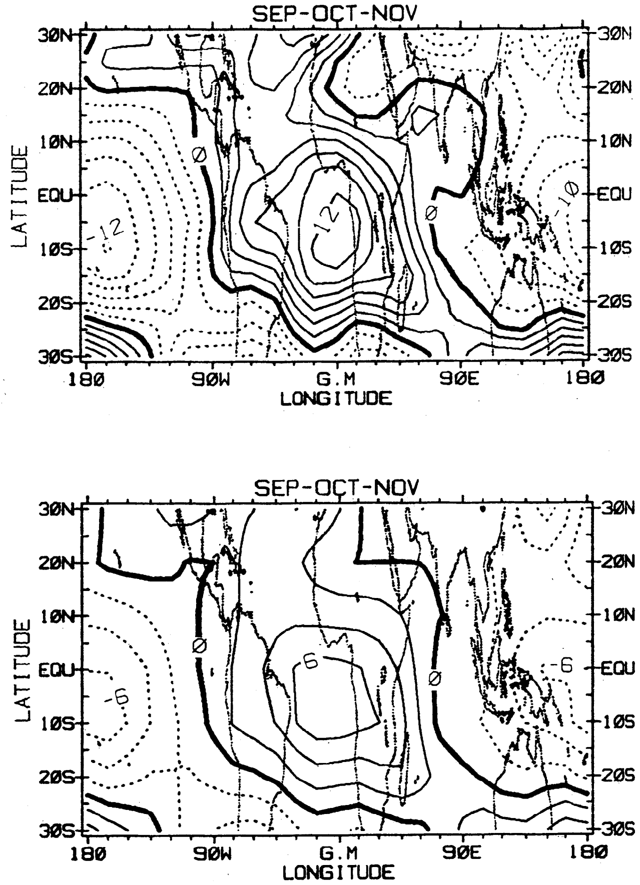

Figure 1. (top) Seasonally averaged (September-November) low-latitude version 7 total ozone mapping spectrometer (TOMS) total ozone and (bottom) 0.3- to 100-hPa NOAA 11 solar backscatter ultraviolet 2 (SBUV2) integrated column ozone anomalies. These 3-month seasonal averages were derived by combining all available data for 1991 and 1992. Anomalies, in Dobson units (DU), represent ozone fields following subtraction of zonal means. Contour intervals are 2 DU.

However, the large wave amplitude in SBUV2 seen in Figure 1 is an artifact of total ozone measurements used in the SBUV first-guess profiles in the lowest three Umkehr layers. The SBUV algorithm [*Fleig et al.*, 1990; *Bhartia et al.*, 1996] allows ozone amount to be calculated in 12 Umkher layers (not independent of one another) defined by pressure range. The first four layers are 253-1013, 127-253, 63-127, and 32-63 hPa, respectively. The other eight layers cover 0.1-32 hPa. In the tropics, the tropopause is near 100 hPa and typically lies within layer 3, so that stratospheric column ozone to a first approximation can be calculated by summing layers 3-12. Unfortunately, SBUV data have very little if any real profile information within layers 1-4. Although summation of layers 1-4 is a good measure of column ozone amount below 30 hPa, the distribution of ozone within these individual layers is constrained in the algorithm by total column ozone measurements.

As a result of the combination of the SBUV vertical weighting functions and inversion algorithm, the distribution of tropospheric ozone associated with the tropical wave 1 anomaly produces a fictitious wave 1 in SBUV2 retrieved lower stratospheric ozone. This lower stratospheric wave is not present in ozone data from other satellite instruments such as SAGE [*Fishman and Larsen*, 1987; *Shiotani and Hasebe*, 1994], or UARS Halogen Occultation Experiment (HALOE) and Microwave Limb Sounder (MLS) [*Ziemke et al.*, 1996]. For example, Figure 2 compares height versus longitude cross sections of ozone zonal anomalies from SBUV2 and version 4 205-GHz MLS for September 1992 centered at 7.5°S. Zonal wave patterns in SBUV2 and MLS are essentially similar at altitudes above, but not below, 20 hPa. SBUV2 below 20 hPa indicates a wave 1 artifact that is clearly not present in MLS. This same scenario between SBUV2 and MLS can be shown for every month of available comparison, from September 1991 through November 1994 (figures not shown).

We note that MLS ozone data at 100 hPa (not plotted in Figure 2) are not recommended for scientific study because of inherent biases caused by being partly climatology. Ozone at 68 hPa were derived by interpolating data between 100 hPa and the lowest true measure-

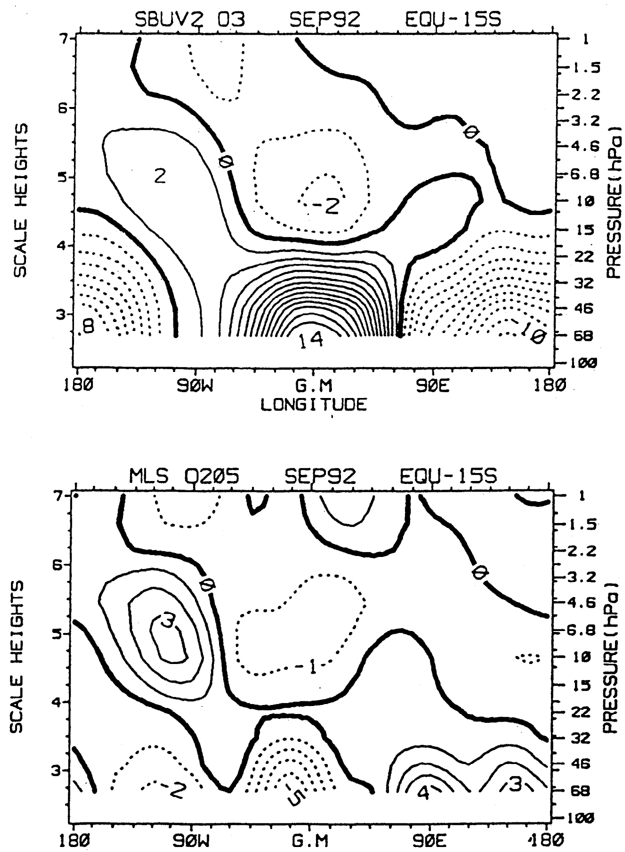

Figure 2. (top) Scale height versus longitude zonal wave anomalies of SBUV2 and (bottom) MLS ozone volume mixing ratio averaged from the equator to 15°S for September 1992. Anomalies were derived by removing zonal averages from data and represent percent of zonal mean mixing ratio.

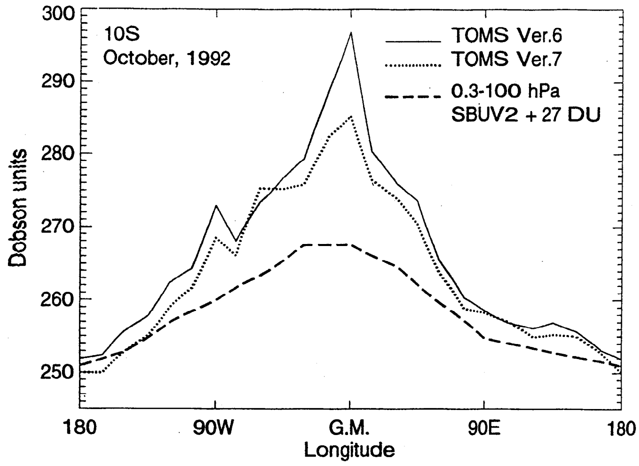

Figure 3. Longitude line plots of version 6 (solid line) and version 7 (dotted line) TOMS total ozone along with 0.3- to 100 hPa stratospheric column ozone derived from NOAA 11 SBUV2 (bold dashed line) for October 1992 at 10°S. For comparison purposes, SBUV2 includes a +27 DU offset to bring all three data fields together near the dateline.

ment level, 46 hPa. (These issues, including extensive validation tests of MLS ozone data, are discussed by *Froidevaux et al.* [1996].)

Despite quality problems with 68- and 100-hPa MLS data, the strong wave 1 feature in SBUV2 in Figure 2 below 20 hPa is within the measurement capability of MLS. *Ziemke et al.* [1996] indicated around 2-3% sensitivity (relative to monthly zonal mean background) of MLS in detecting ozone wave anomalies in the low to middle stratosphere. The quality of MLS ozone data below 46 hPa is not critical in this study in order to emphasize our main objective. For example, SBUV2 ozone higher up at 30 hPa in Figure 2 shows a robust wave 1 pattern that is not present in UARS MLS, UARS HALOE, or SAGE data. This implies directly that the SBUV2 tropical wave feature is an artifact and not real. (At 30 hPa, data from all of these latter non-SBUV instruments are of good quality.)

It can be shown that SBUV2 data show the same zonal structure in all four lowest Umkehr layers, suggesting that each is constrained by total ozone measurements. A preliminary study of the SBUV algorithm suggests that even if the wave structure is present in only one of these four layers, the SBUV algorithm will tend to produce similar structure in all of the four layers (L. Flynn, personal communication, 1997).

Figure 3 compares longitude line plots of version 6 and version 7 Nimbus 7 TOMS total ozone along with 0.3- to 100 hPa stratospheric column ozone derived from NOAA 11 version 6 SBUV2 for October 1992 at 10°S. In an effort to better visually compare zonal structural differences between SBUV2 and TOMS, +27 DU was added to SBUV2 in Figure 3, bringing SBUV2 up to TOMS near the dateline.

The large +15 DU (peak-to-peak) wave 1 artifact in SBUV2 in Figure 3 has important consequences when subtracting SBUV2 stratospheric column ozone from total ozone to estimate TOR. (It makes estimates of TOR weaker than they actually are in the tropical Atlantic region.) It is also apparent in Figure 3 that there are sizeable differences between version 6 and version 7 TOMS ozone, with version 6 larger (positive offset) relative to version 7. The +10 DU offset near 0° longitude in Figure 3 is caused by improvements in version 7 for low marine stratus clouds in the region [*Thompson et al.*, 1993].

In conclusion, this investigation shows that lower stratospheric ozone obtained from SBUV and used to determine tropospheric ozone is biased by total ozone measurements used in the SBUV inversion algorithm. This follows from total ozone measurements used to derive first-guess profiles in the lowest three Umkehr layers. The resulting bias can be significant, as was apparent in the south Atlantic anomaly example shown in this study. SBUV integrated from 0.3 to 100 hPa indicated a strong zonal wave 1 pattern in stratospheric column ozone with amplitude ~15 DU (peak to peak). This algorithm artifact has obvious consequences when using SBUV to estimate tropospheric ozone.

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